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INITIAL RESULTS FROM HF PROPAGATION STUDIES DURING SOLID SHIELD--ETC(U)
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In May 1981, NRL personnel manned two (2) receiver sites located at Norfolk, Virginia and Ft. Bragg, North Carolina to obtain 24 hr. a day coverage of data available from an oblique sounder network put into operation to support the DoD Solid Shield exercises. The resulting photographic data were scaled to obtain the maximum useable frequency (MUF) vs time for each circuit recorded. One circuit was selected as a control path to provide an update to a model which predicts the MUF. Upon obtaining an update

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20. ABSTRACT (Continued)

of this model using the control path, the model was used to compute MUF's for other paths for which data was available. Under the geomagnetically disturbed conditions which prevailed during Solid Shield, the update provided accuracies of about 1 MHz RMS with a new update required about every 3 hours to maintain this accuracy. These results may have profound implications on the design and ultimate operation of automated frequency management systems.

CONTENTS

INITIAL RESULTS FROM HF PROPAGATION STUDIES DURING SOLID SHIELD

1.0 INTRODUCTION

1.1 Objective

The objective of this report is to present initial results of recent efforts undertaken by NRL to examine the viability of coupling oblique sounding equipment to computer based HF propagation assessment systems in order to provide a greatly improved frequency management capability. Oblique sounder data collected during the Solid Shield exercises, which took place between 3 May and 20 May, 1981, will form the basis of this examination.

1.2 Results

The initial results were obtained from data collected on 7 and 8 May. During these two days solar activity was high and the magnetic field was active. This analysis indicates that under these adverse conditions propagation assessment and forecasting of the maximum usable frequency (MUF) could be performed with an error of about 1 MHz RMS by providing an update to a model of MUF (MINIMUF 3.5) approximately every three (3) hours. The essence of the update scheme investigation reported herein was to utilize measurements from the B R Communications AN/TRQ-35 oblique sounding equipment to provide an update to the NOSC PROPHET system which uses MINIMUF 3.5 to compute MUF. An update employing one path as a data source was accurately projected to other paths of interest in all instances in this initial work with the Solid Shield data base.

1.3 Background

In the past year, NRL has been investigating the possibility that large increases in the accuracy of HF propagation assessment and forecasting might accrue by employing schemes to update computerized models of the HF propagation channel. The cornerstone of the validation procedure is a direct evaluation of the HF channel between a transmitter and receiver. In order to accomplish this task at a minimum cost, the channel evaluation is obtained by utilizing existing oblique sounding equipment employed by the military in various operations. A recent exercise utilizing this equipment was Solid Shield which was conducted during May, 1981. To support this exercise, oblique sounding transmitters and receivers were deployed at stations along the East Coast of the United States and several ships operating in the Atlantic Ocean were equipped with receivers and spectrum monitors.+

+The oblique sounding transmitters were configured to begin a 2-30 MHz sweep each in a specific 5 minute time slot for each 15 minute time period. Hence, an individual transmitter had a 15 minute duty cycle. Two (2) transmitters setup during Solid Shield (Shaw AFB and Hurlbert Field) were on the same 5 minute time slot. The receivers were synchronized in time with the desired transmitter for each 5 minute time slot. Spectrum monitors are essentially noise receivers which scan each of 9333 channels in the 2-30 MHz band every 11 seconds. The spectrum monitor stores in memory the occupancy of each channel and these data may be displayed in either a 100 kHz or 500 kHz band centered on the frequency desired by the operator. Hence, the specturm monitor provides a picture of the interference environment local to the place in which it is operating.

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During this exercise, NRL deployed personnel to two receiver sites in order to obtain around-the-clock data in support of the project. Between 3 and 19 May, 1981, NRL personnel were located at NAVCAMSLANT in Norfolk and at a field site on Ft. Bragg in North Carolina. Since there is currently no way to automatically record data, the workers photographed the oblique sounder receiver display for each path sounded. Transmitters were located at Hurlbert Field, Florida; Bogue Field at Camp Le Jeune in North Carolina; Shaw AFB, South Carolina; and at Driver, Virginia. The time sequencing of the oblique sounder transmitters for Solid Shield was inflexible and basically awkward for our purpose. In order to obtain better area coverage as well as a larger menu of circuits, NRL contacted the Air Force at MacDill AFB, Florida to put another transmitter on the air. That transmitter was configured to transmit the full 2-30 MHz scan every five (5) minutes (a 5 minute duty cycle) so that it could be selected as one of three transmitters for any time slot for which there was no transmitter operating in the original net. In fact, during one period of time, the Bogue Field (Camp Le Jeune) transmitter went off the air and the MacDill transmitter was easily substituted in its place at the Norfolk receiver site. The MacDill transmitter proved to be extremely useful since the data output was greatly increased at the Norfolk site.

Figure 1 is a great circle map showing the location of the transmitters and receivers for the period addressed by the NRL model update experiment. Table 1 indicates the path parameters for this sounder network where the bearing of each transmitter from the receiver as well as the ground range in km. is indicated. These circuits are generally short and none were strictly East-West or North-South in orientation.

Table 1 — Path parameters for oblique sounder network

FROM TO	NORFOLK	FT. BRAGG
Hurlbert Field, FL (T) 30.3°N 86.4°W	 236.4° 1176 km	 236.0° 904 km
Shaw AFB, SC (T) 33.6°N 80.3°W	 229.4° 500 km	 223.6° 226 km
Bogue Field, NC (T) 34.4°N 76.4°W	 184.8° 245 km	 110.5° 216 km
MacDill AFB, FL (T) 27.5°N 82.3°W	 211.3° 1163 km	 203.6° 915 km
Driver, VA (T) 36.7°N 76.5°W	 292.7° 29 km	 46.1° 260 km
Ft. Bragg, NC (R) 35.1°N 78.6°W	 233.1° 273 km	

Fig. 1 — Geometry of the oblique sounder circuits employed by NRL during Solid Shield plotted on a great circle map

2.0 DISCUSSION

2.1 Experimental Approach

The essence of the NRL approach involves the selection of a specific oblique sounder circuit (designated hereafter as the "control path") which is used as a data source to provide an update to a computer algorithm which can perform HF propagation assessment* and forecasting** over a local operational area. The computer algorithm used is a model of MUF called MINIMUF 3.5 which is resident in the NOSC PROPHET system.*** In order to test this concept experimentally, oblique sounder data from a number of additional experimental circuits which are operating simultaneously with the control path are required. Data of this type was obtained during Solid Shield. NRL used the sounder circuit between Hurlbert Field and Norfolk as a control path while the other transmitter and receiver combinations served as experimental circuits. The channel configuration of the receiver at each of the receiver sites is shown in figure 2. Photographic data from these receivers form the data base obtained during Solid Shield.

NRL identified NAVCAMSLANT in Norfolk as the primary site for the data collection effort. NAVCAMSLANT was the logical choice since it is responsible for frequency management decisions for the Atlantic fleet. This site selection, therefore, provided the greatest opportunity to learn more about the various operational problems faced by Naval frequency managers as well as to potentially impact the frequency management process itself. Unfortunately, some key operational personnel did not appreciate these goals and unnecessarily interferred with the data collection effort. This difficulty was the major contributor to a less than optimum data set for the Norfolk site. A summary of the Norfolk experiment log is included as Appendix A indicating conditions, problems, etc.

The Ft. Bragg receiver, however, was completely under NRL control and an optimum data set was obtained. After the Hurlbert transmitter site exercised the planned shut-down on 13 May, the NRL personnel at Ft. Bragg switched the receiver to Shaw AFB for the remainder of the period in order to maintain a full 3 station data set.

For the purpose of analysis, the Norfolk to Hurlbert path was chosen as the control path for the first half of the experimental period and all other circuits were selected as experimental circuits against which the model update scheme was tested. The initial data analysis presented herein will utilize this arrangement for data from May 7 and 8, 1981. As the analysis proceeds to the later data, the Ft. Bragg to MacDill path will probably be selected as the control path since the Hurlbert transmitter was shut down on 13 May. All other paths will act as the experimental circuits. A future report will discuss this altered approach in detail.

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* The term assessment as used herein is defined as the determination of the properties of the channel as they exist at the present time.

** The term forecast is defined as the determination of the channel properties as they are expected to be in the near future, extending out in time to as much as 24 hours ahead of the present.

*** MINIMUF 3.5 is a small module of computer code consisting of about 80 statements in BASIC which computes Maximum Usable Frequency (MUF) over a high frequency (HF) circuit. MINIMUF is a semi-empirical simple relaxation model driven by a cos x function where x is the zenith angle of the sun at mid-path. Several adjustable parameters incorporated in the model were set by fitting to a data base of oblique sounder data. This model was developed by NOSC and is incorporated in the NOSC propagation forecasting (PROPHET) system.

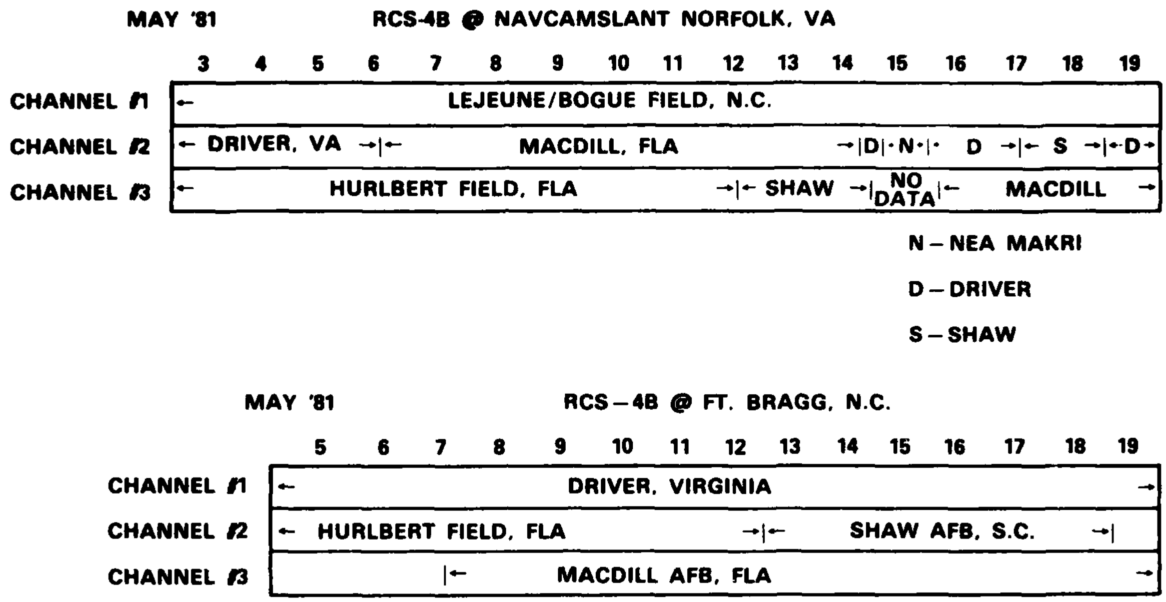

Fig. 2 — Receiver channel configuration at the Norfolk and Ft. Bragg sites for the period 3 — 19 May, 1981

2.2 The Solar Background

During the first half of May, 1981, solar activity was somewhat increased. This fact is illustrated by the next several figures. Figure 3 is a plot of both the daily sunspot number as obtained from the Space Environment Service Center (SESC) at NOAA in Boulder Colorado and the five (5) day running average sunspot number. Figure 4 is a plot of another indicator of solar activity, the solar 10.7 cm flux as measured at Ottawa. Plotted are both the daily values and the 5-day running average. A running average of 10.7 cm flux is the preferred parameter for driving PROPHET in the un-updated mode.(1)

Figure 5 is a plot of solar flare activity for the month of May. The height of the individual bars in figure 5 represents the relative height of the peak of each solar flare in energy output as indicated by SESC during the period. These figures show that solar activity was high during the full term of the experimental period between 3 and 19 May with the peak period of activity between 7 and 14 May.

The effect of the increased solar activity and solar flares in particular is to increase absorption in the lower ionosphere of high frequency (HF) radiowaves. In addition, maximum useable frequencies (MUF) quite often are increased due to enhanced F-layer ionization. However, this MUF enhancement was not observed in the data selected for initial analysis. In fact, MUF's were generally depressed and were not accurately predicted by the standard MINIMUF 3.5 model.

A clue to this behavior may be given in figure 6. During the month of May, the earth's magnetic field was also active. This activity is indicated by the Kp index which ranges in values from 0-9. Simply put, increased magnetic activity leads to the increased probablity of ionospheric storms. The chief fallout from ionospheric storms is a reduction in F-layer critical frequencies and increased absorption. Hence maximum usable frequencies may be depressed and the HF band can be generally constricted.(2) This is probably the effect we are observing. Since the MINIMUF model currently has no provision to factor in magnetic activity, it does not operate as well in the un-updated mode for this data set. Further, in the mode whereby MINIMUF is updated at one point and required to provide a prediction for a full 24 hour day the model does not perform as well as in previous data sets.(3,4)

The diurnal frequency variation of the channel as modified by the solar and geomagnetic activity is so flat, in fact, that it may have been possible to operate HF communications links very effectively at a single frequency for the full 24-hour day. This may have been done quite well by Navy communicators since they have the high power transmitters to overcome increased absorption witnessed during this active period.

2.3 The Un-Updated Model

The raw material required to validate the update of a propagation model is HF oblique sounder (channel evaluation) data, currently in the form of polaroid photographs, taken from the display of the RCS 4B receiver of the AN/TRQ-35 Tactical Frequency Management System (TFMS). When the receiver is monitoring three transmitters, the system is typically setup to receive one transmitter every 5 minutes repeating the cycle of 3 transmitters every 15 minutes. Hence, the operator must take one photograph approximately every 5 minutes in order to obtain a full data set. The photographs are brought back

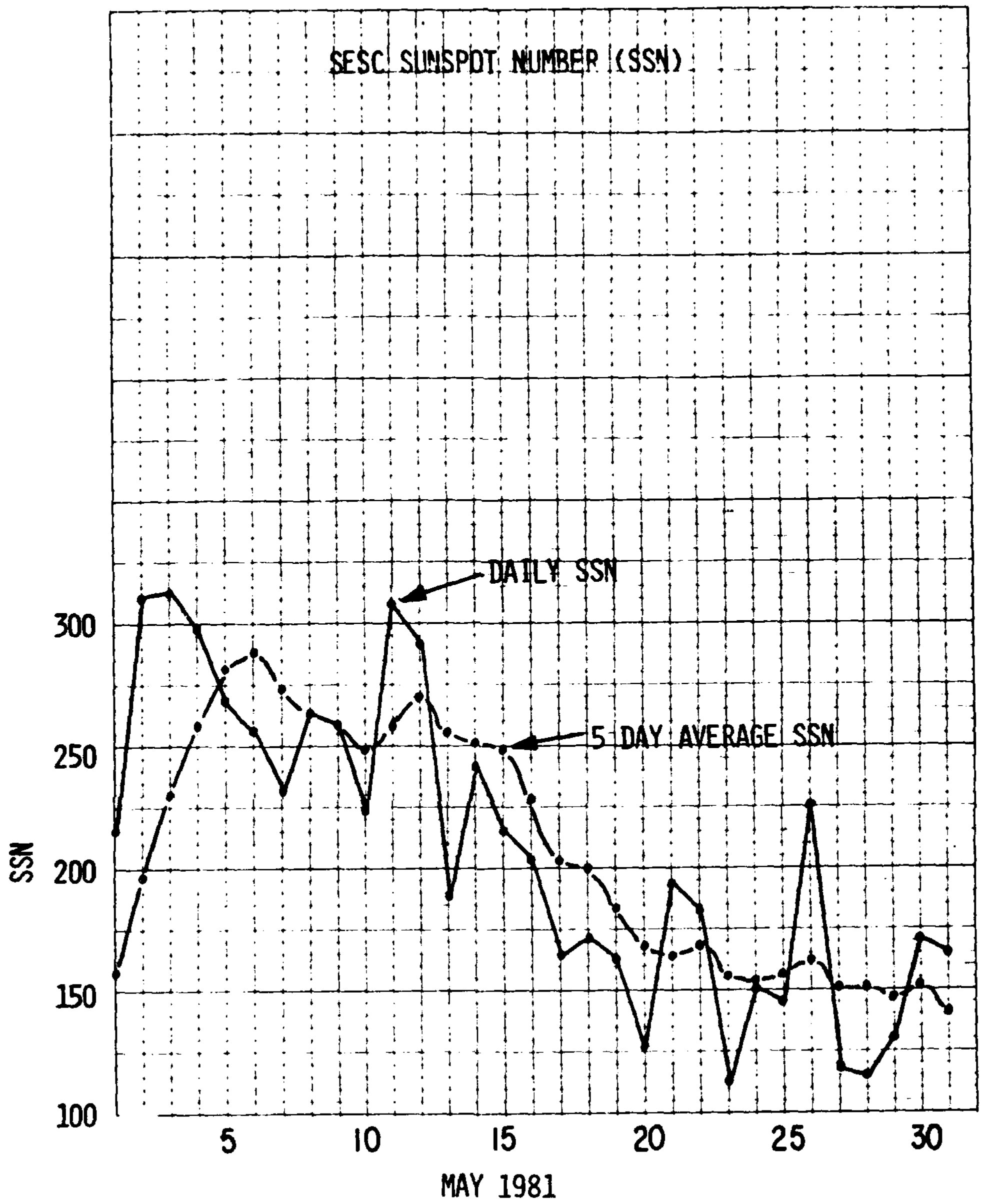

Fig. 3 — Solar activity background for Solid Shield as indicated by daily sunspot number and the 5 day running average sunspot number as obtained from SESC, Boulder, Colo.

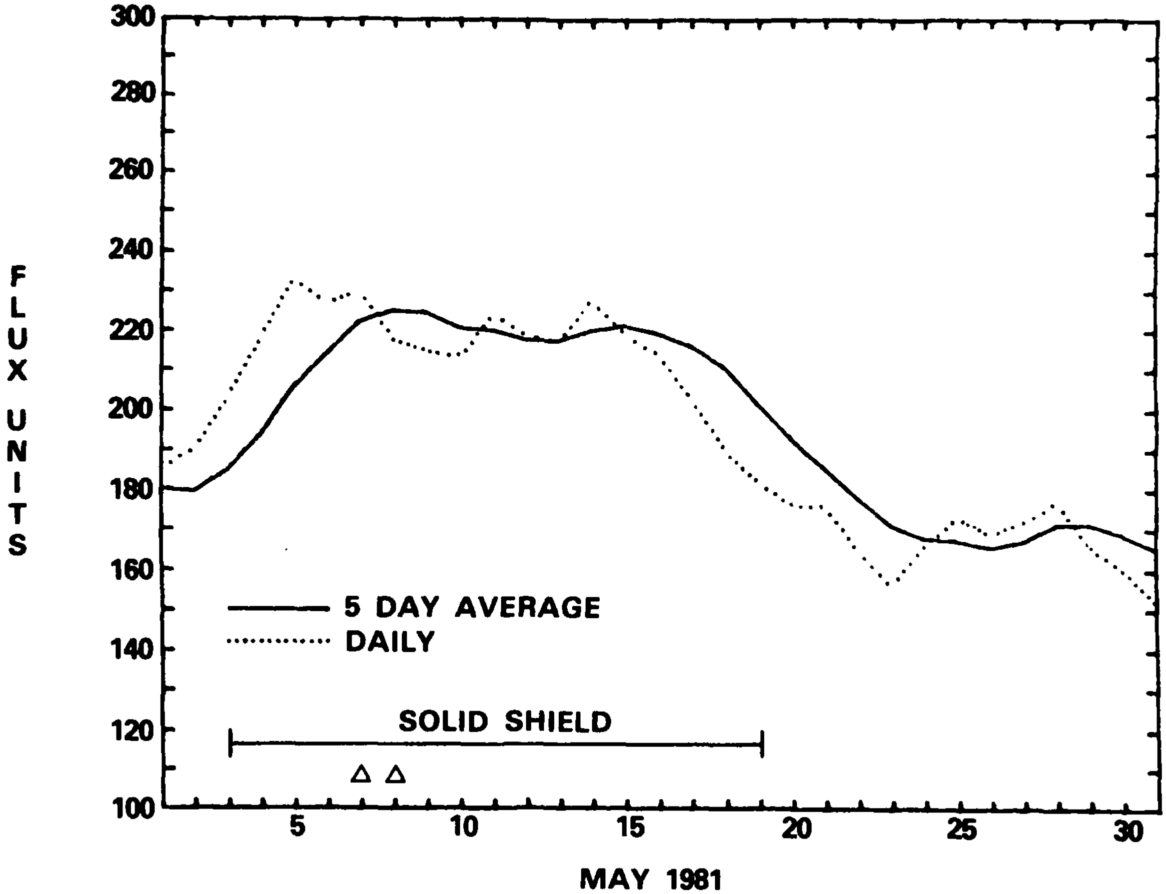

Fig. 4 — Solar activity background for Solid Shield as indicated by daily 10.7 cm flux and the 5 day running average 10.7 cm flux

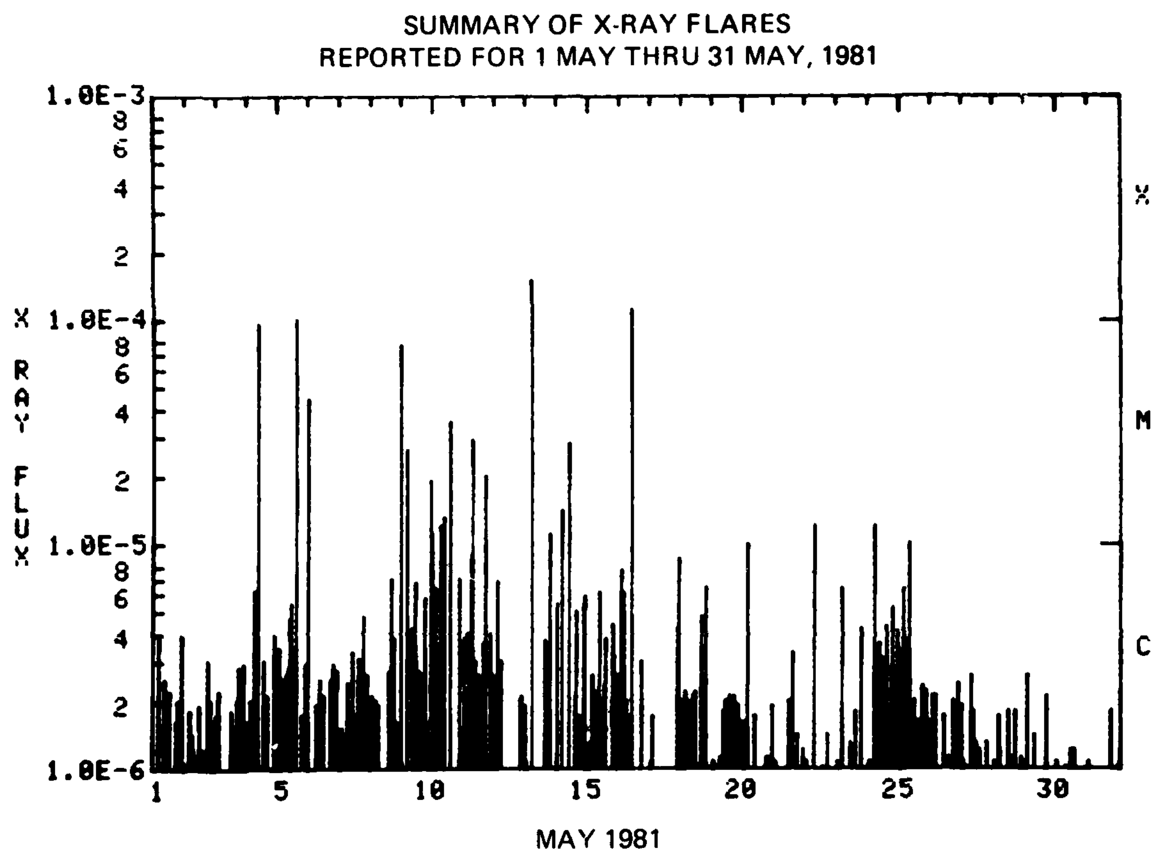

Fig. 5 — Solar x-ray flare activity for May 1981 as obtained from the "Solar Geophysical Data, Preliminary Report"

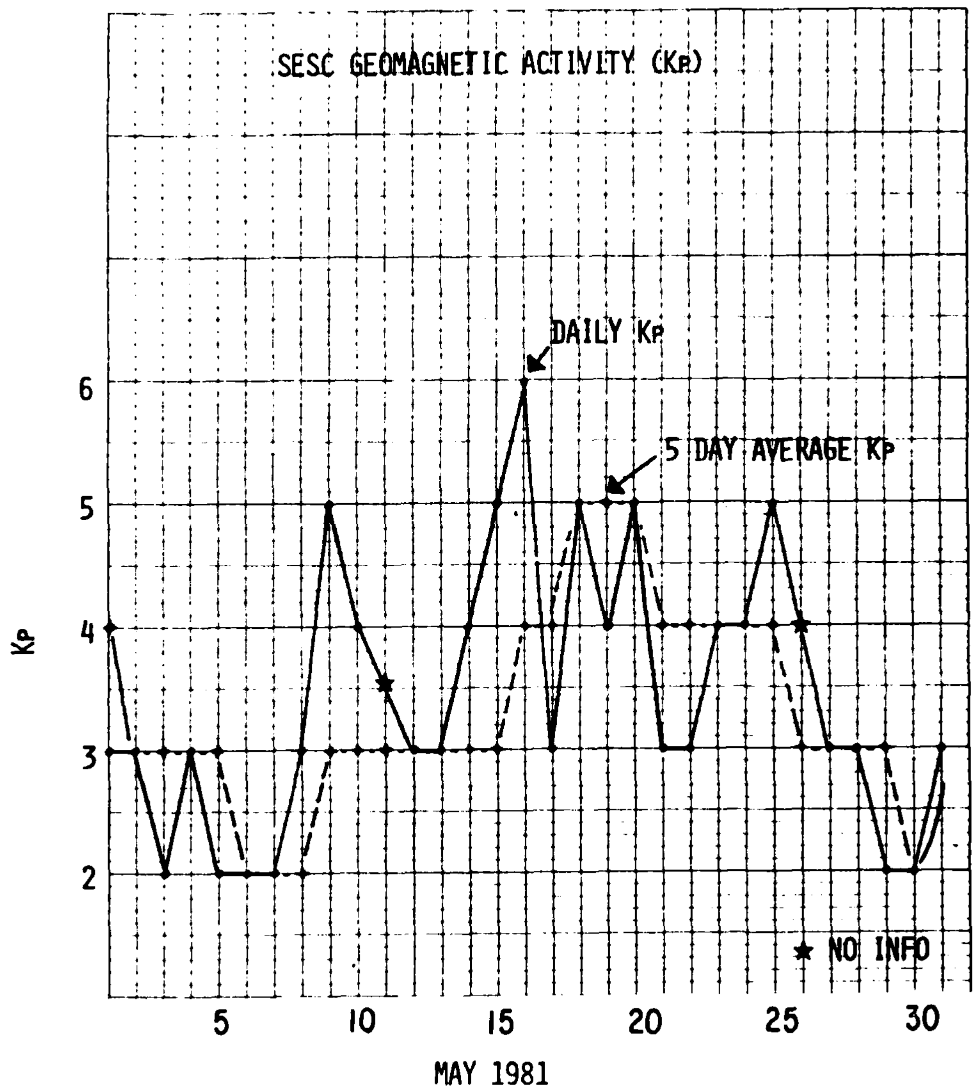

Fig. 6 — Magnetic activity for May 1981 as represented by the index Kp. This index indicates moderate activity in the middle of the month.

to NRL and scaled to obtain the maximum usable frequency (MUF), the band of optimum transmission frequencies (FOT band) and the lowest usable frequency (LUF). The MUF for our purposes is defined as the highest frequency indicated on the display whereby energy is being received from the transmitter. The optimum transmission frequency band is defined as that band of frequencies which exhibit no multi-path and which show a high signal strength. The lowest useable frequency (LUF) is defined as the lowest observed frequency on the ionogram.

For the preliminary analysis, data collected on May 7 and 8, 1981 was selected. Figure 7 is a plot of the scaled MUF, LUF, and FOT band for data obtained at the Norfolk receiver. During this period, the transmitters at Hurlbert Field, MacDill AFB, and Camp Le Jeune were being monitored by the NRL personnel at the Norfolk site. The outstanding feature of the data displayed here is the flatness of the diurnal variation of the channel. As discussed earlier, this depression of the range of MUF's between day and night is probably due to the existence of ionospheric storms. The Camp Le Jeune to Norfolk data is a good example of this. Notice that a constant 8 MHz frequency should have performed quite well over that circuit for the two day period of time shown in this figure. This is contrary to the normal mode of selecting a higher frequency during the day when the MUF is increased and a lower frequency at night when the MUF is lower in order to maintain the HF circuit.

The Solid Shield data set provided the first opportunity to examine the viability of the model update technique when a complete circuit is displaced from the control circuit from which the update is being obtained. This aspect of the problem will be illustrated by utilizing data obtained at the Ft. Bragg receiver. Hence, figure 8 is presented which shows the diurnal variation of the several channels monitored by the Ft. Bragg receiver. Shown are circuits to Ft. Bragg from Hurlbert Field, MacDill AFB, and Driver, Virginia. Much of the MacDill data is missing on the day of May 7 because the personnel at the Ft. Bragg site could not time synchronize with the MacDill transmitter due to the lack of a WWV receiver. The displaced circuit question will be discussed in more detail shortly, but one suspects it should work if the model is a good one since simply overlaying figures 7 and 8 shows a large amount of coordinated variability in the MUF's with differences being basically geometrical in nature.

In order to demonstrate the performance of the unupdated MINIMUF 3.5 model under ionospheric storm conditions, figure 9 is presented. This figure demonstrates the difference between MINIMUF predictions of MUF and the actual measured maximum usable frequency between Hurlbert Field and Norfolk. The top plot in the figure shows the difference between the actual measured MUF and the model calculation utilizing the five day running average of 10.7 cm flux to drive MINIMUF. The RMS error on May 7 is 4.55 MHz and on May 8 is 6.13 MHz. The centered set of plots shows the performance of the model against the measured MUF using the one day 10.7 cm flux as the driving parameter for the model. For 7 May the RMS error was 3.45 MHz and for 8 May it was 6.27 MHz. Note here that the one day 10.7 cm flux yielded an improvement over the 5 day average for the May 7 data but there was a slight degradation using the one day 10.7 cm flux for the May 8 data set. A set of plots corresponding to the top two plots in figure 9 for the other five paths is included as Appendix B.

Since the MINIMUF model has a characteristic diurnal variation for the MUF, it is useful to determine what absolute minimum RMS error can be obtained from this model for each data set. This calculation is shown on the bottom

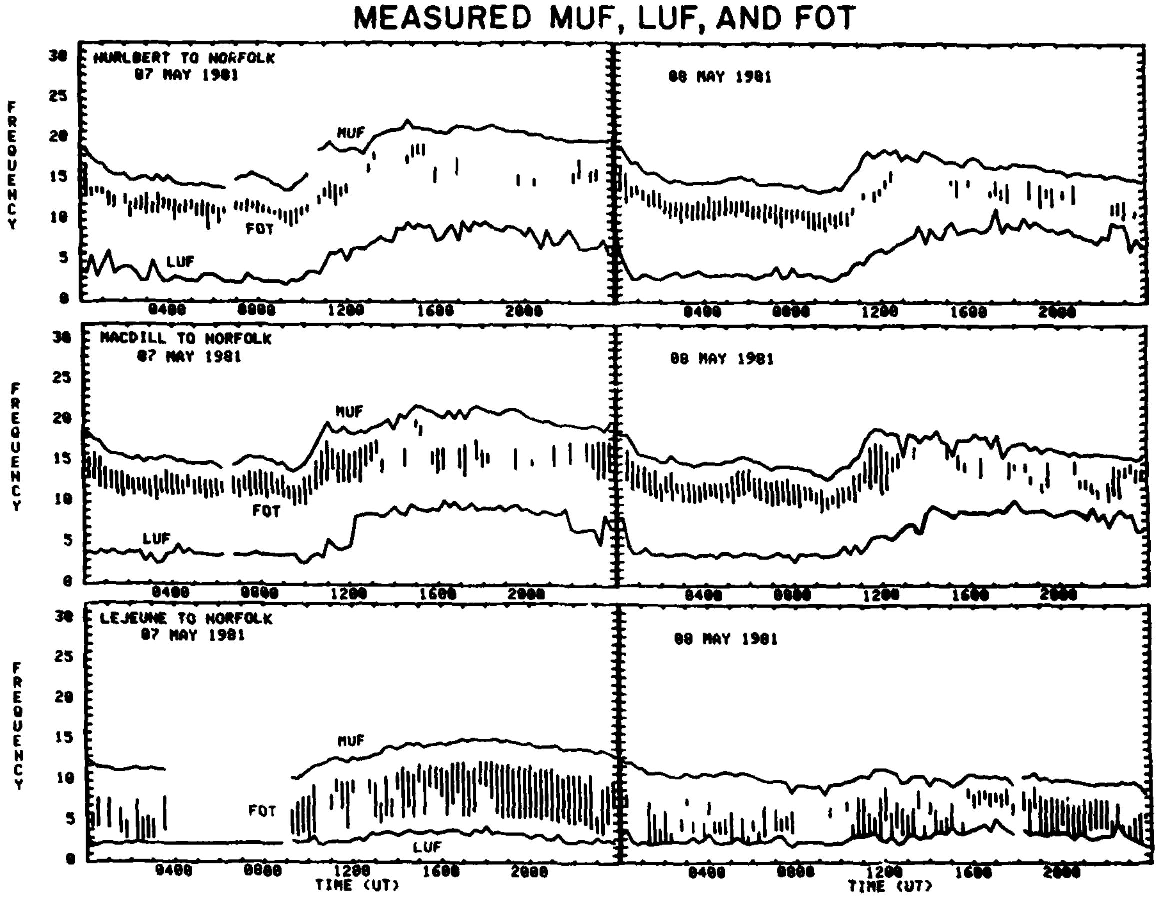

Fig. 7 — Maximum observed frequencies, lowest observed frequencies and frequencies of optimum transmission as scaled from photographs taken of the TRQ-35 receiver located at Norfolk.

MEASURED MUF, LUF AND FOT

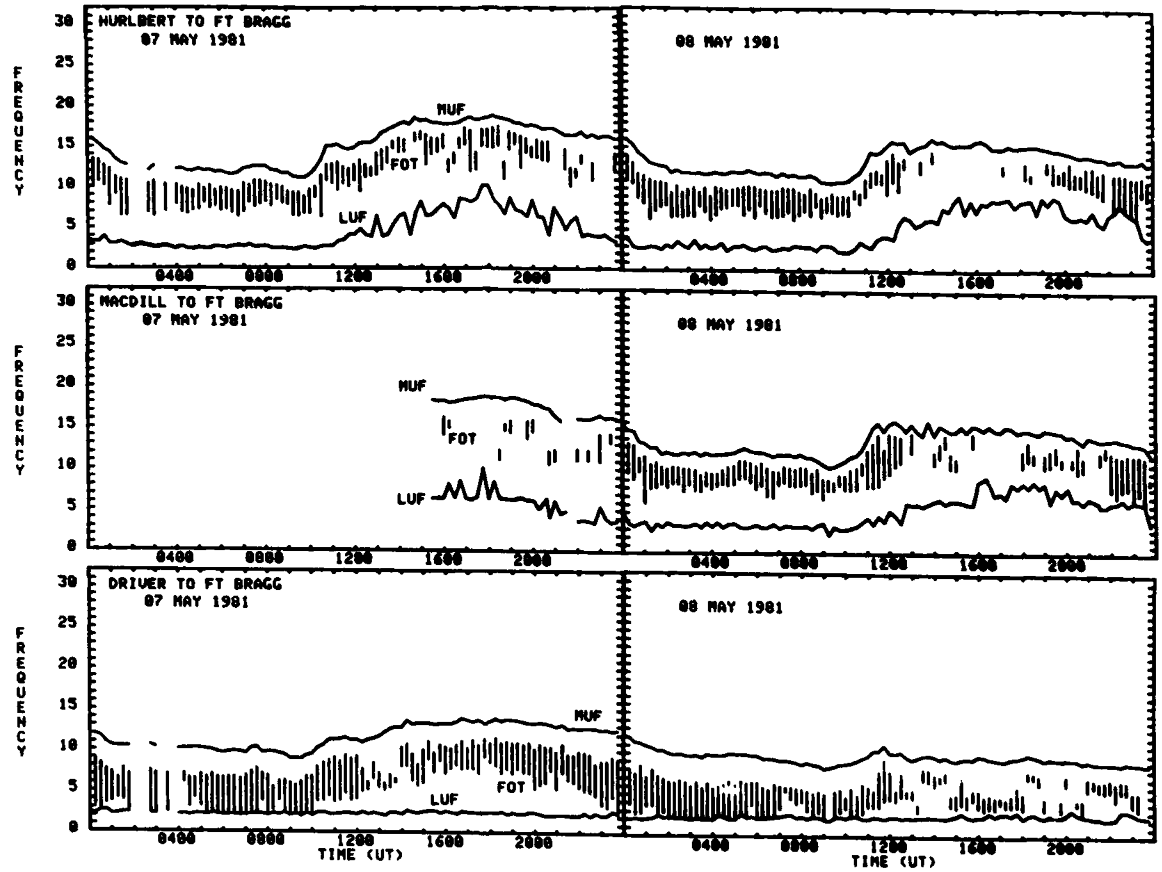

Fig. 8 — Maximum observed frequencies, lowest observed frequencies and frequencies of optimum transmission as scaled from photographs taken of the TRQ-35 receiver located at Ft. Bragg.

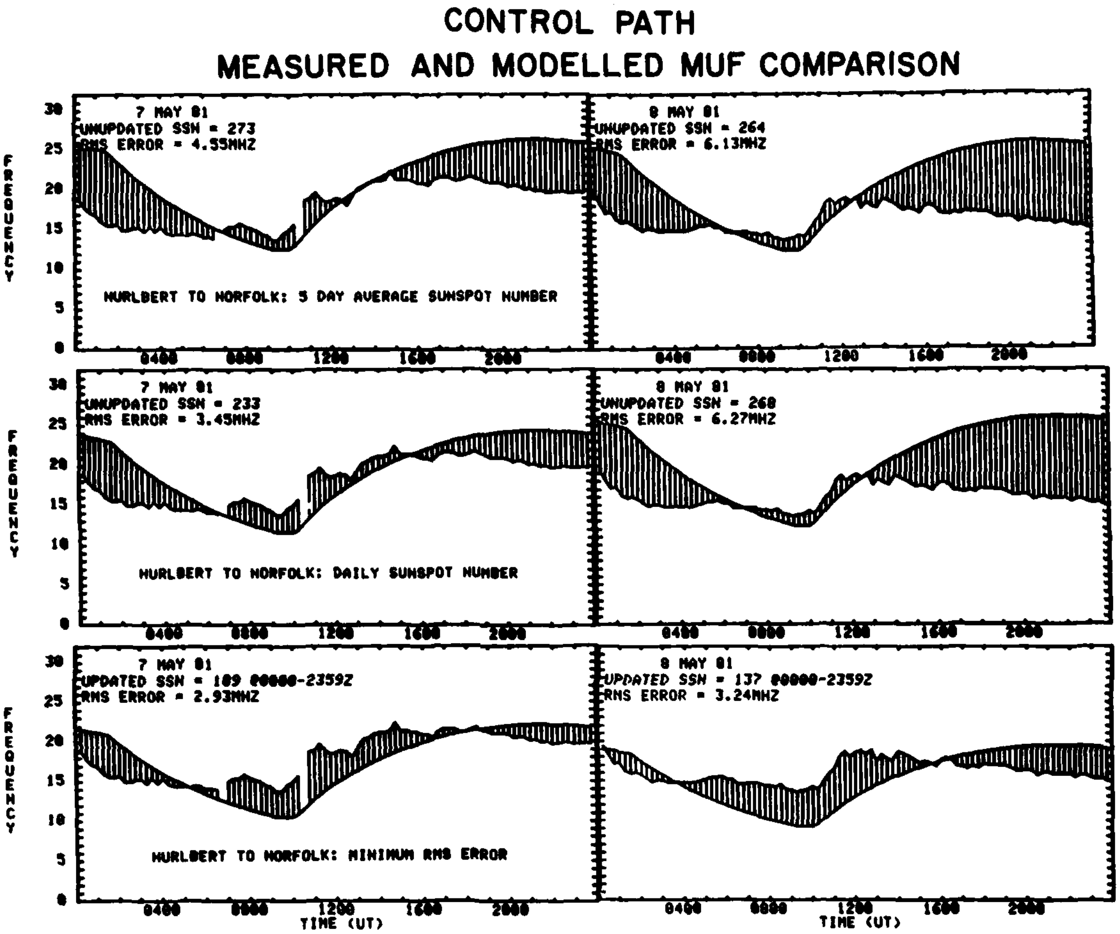

Fig. 9 — A comparison of the measured and modelled MUF for the control path (Hurlbert Field to Norfolk) for the 5 day running average and daily sunspot numbers as driving parameters for the model. The bottom plot indicates the best fit that is possible for the model against the data set as obtained by deriving a sunspot number which yields a minimum RMS error for the given 24-hour period.

set of plots in figure 9 for the Hurlbert to Norfolk path. On 7 May, MINIMUF was run in order to find the minimum possible RMS error for the total day. That minimum was 2.93 MHz. For 8 May, the minimum RMS error was 3.24 MHz. Hence, this bottom plot shows the absolute best one could do with MINIMUF 3.5 given the constraints imposed by the model and that the total day must be fit at once. This same calculation is used in following tables when the success of the model update scheme is discussed.

2.4 The Single Point Update

Tables II - VII list the RMS errors associated with various means of extracting a single point model update. The RMS errors shown in these tables were derived with the constraint that once the "effective" 10.7 cm flux for an update is determined* using either a single data point or data points covering a single span of time, the RMS error is then calculated for the complete 24-hour day. Each table indicates the date for the data set and the circuit for which the data was derived. The RMS error is that of the model compared to the measured MUF using both the one day sunspot number and the five day running average sunspot number to drive the model. These two numbers are the first two lines of the table and are indicated as "unupdated" calculations in the mode column. The RMS error for the updated model comprises lines following the unupdated data and is based on the model driven by the effective 10.7 cm flux as derived from minimizing the RMS error in the span of times indicated in the time column. For example, in Table II the third line shows an RMS error of 2.93 MHz which is derived by minimizing the RMS error over the span of time 0000Z - 2359Z. This is actually the absolute minimum RMS error that can be obtained by utilizing the MINIMUF model under the circumstances indicated in the table. The next line in the table shows an RMS error of 6.9 MHz. This was derived by forcing MINIMUF to fit the one MUF measurement taken at 1000Z and using the resulting effective 10.7 cm flux to drive the calculation for the whole day. 5.55 MHz RMS error in the next line is obtained by forcing MINIMUF to fit at 1200Z. The last line for 7 May shows a 4.64 MHz RMS error. This was obtained by computing the effective 10.7 cm flux which yields a minimum error for MINIMUF for the two hour set of MUF measurements between 1200Z and 1400Z. Table II lists the RMS errors derived in this manner using the Hurlbert to Norfolk circuit as the control path for 7-8 May.

The control path provides the basis for the update via the "effective" 10.7 cm flux. This "effective" index is then used to drive MINIMUF computations for the experimental paths. Tables III - VII indicate the RMS errors resulting from the MINIMUF calculation over the experimental path indicated at the top of the table. These tables show a mixed result in terms of the success of the update for providing an improved 24 hour forecast of the MUF. The MacDill to Norfolk path has a geometry very similar to the control path (See Table I and figure 1). As a result, the statistics for this path as shown in Table III are very similar to those in Table II. Over both paths, the best fit to the measured MUF which could be obtained using MINIMUF is about 2.95 MHz RMS and 3.24 MHz RMS for May 7 and 8 respectively. Generally,

*The model update is performed using MINIMUF simply by re-computing MINIMUF while changing the 10.7 cm flux until the calculation yields a fit to the MUF measured by the sounder. If a span of times is used, the calculation is performed until a minimum RMS error between MINIMUF and the measurements is reached. The new resulting 10.7 cm flux is then used to drive other calculations. This new 10.7 cm flux, which is the basis of the update, will be referred to as the "effective" 10.7 cm flux.

the errors in Table III are lower than in Table II, but the variations from situation to situation are highly correlated. This type of behavior suggests that a properly updated model which reduces the error along one path should reduce the error in a like manner along another similar path in the vicinity. However, these RMS errors show generally worse results obtained by updating the model as compared to using the 5 day running average 10.7 cm flux. Only the update using a MUF measurement at 1400Z (10:00 LMT) yields an improvement.

Table IV lists the RMS errors for the Bogue Field (Camp Le Jeune) to Norfolk path. Although this path is geometrically very different from the control path, the computed RMS errors show the same trends as the previous two tables. Notice that the best update again occurs at 1400Z.

Tables V - VII are the result of employing the update scheme over circuits whose termini are displaced from the control circuit. Table V indicates RMS errors obtained by using the effective 10.7 cm flux as derived from the control path to drive the calculation over the Driver Va. to Ft. Bragg circuit. Again the 1400Z update yields a slightly better result as compared to the 5-day running average, but a worse result than the actual 1-day 10.7 cm flux. Table VI gives the errors from the Hurlbert to Ft. Bragg path and Table VII the MacDill to Ft. Bragg path. In all cases the 1400Z yields a better forecast than the 5-day average, but the improvement is considered slight.

These underwhelming results force us to investigate the issue of temporal perishability of the model update under disturbed conditions. In other words, it appears from the statistics in the preceeding tables that the temporal perishability of the model update is somewhat less than 24 hours. Hence, the following section.

Table II — Control path — Hurlbert Field, FL to Norfolk, VA

DATE	RMS ERROR(MHz)	MODE	TIME (Z)	10.7 CM FLUX
7 May 1981	4.55	UNUPDATED 5 Day		329
	3.45	UNUPDATED 1 Day		282
	2.93	Minimum	0000 - 2359	233
	8.19	UPDATED T(.25)	1000	461
	5.55	UPDATED T(.25)	1200	366
	4.51	UPDATED T(.25)	1400	328
	5.69	UPDATED T(4)	1000 - 1400	371
	4.64	UPDATED T(2)	1200 - 1400	333
8 May 1981	6.13	UNUPDATED 5 Day		318
	6.27	UNUPDATED 1 Day		323
	3.24	Minimum	0000 - 2359	180
	9.13	UPDATED T(.25)	1000	421
	7.43	UPDATED T(.25)	1200	362
	4.43	UPDATED T(.25)	1400	257
	6.27	UPDATED T(4)	1000 - 1400	323
	5.25	UPDATED T(2)	1200 - 1400	287

Table III — MacDill AFB, FL to Norfolk, VA

DATE	RMS ERROR(MHz)	MODE	TIME (Z)	10.7 CM FLUX
7 May 1981	4.33	UNUPDATED 5 Day		329
	3.33	UNUPDATED 1 Day		282
	2.93	Minimum	0000 - 2359	238
	7.86	UPDATED T(.25)	1000	461
	5.30	UPDATED T(.25)	1200	366
	4.30	UPDATED T(.25)	1400	328
	5.43	UPDATED T(4)	1000 - 1400	371
	4.42	UPDATED T(2)	1200 - 1400	333
8 May 1981	5.75	UNUPDATED 5 Day		318
	5.88	UNUPDATED 1 Day		323
	3.22	Minimum	0000 - 2359	189
	8.67	UPDATED T(.25)	1000	421
	7.01	UPDATED T(.25)	1200	362
	4.15	UPDATED T(.25)	1400	257
	5.88	UPDATED T(4)	1000 - 1400	323
	4.91	UPDATED T(2)	1200 - 1400	287

Table IV — Camp Lejeune (Bogue Field), NC to Norfolk, VA

DATE	RMS ERROR(MHz)	MODE	TIME (Z)	10.7 CM FLUX
7 May 1981	2.01	UNUPDATED 5 Day		329
	1.72	UNUPDATED 1 Day		282
	1.72	Minimum	0000 - 2359	284
	4.18	UPDATED T(.25)	1000	461
	2.54	UPDATED T(.25)	1200	366
	1.99	UPDATED T(.25)	1400	328
	2.62	UPDATED T(4)	1000 - 1400	371
	2.05	UPDATED T(2)	1200 - 1400	333
8 May 1981	3.70	UNUPDATED 5 Day		318
	3.78	UNUPDATED 1 Day		323
	2.29	Minimum	0000 - 2359	193
	5.47	UPDATED T(.25)	1000	421
	4.45	UPDATED T(.25)	1200	362
	2.76	UPDATED T(.25)	1400	257
	3.78	UPDATED T(4)	1000 - 1400	323
	3.20	UPDATED T(2)	1200 - 1400	287

Table V — Driver, VA to Ft. Bragg, NC

DATE	RMS ERROR(MHz)	MODE	TIME (Z)	10.7 CM FLUX
7 May 1981	2.39	UNUPDATED 5 Day		329
	1.76	UNUPDATED 1 Day		282
	1.58	Minimum	0000 - 2359	248
	4.68	UPDATED T(.25)	1000	461
	3.02	UPDATED T(.25)	1200	366
	2.37	UPDATED T(.25)	1400	328
	3.10	UPDATED T(4)	1000 - 1400	371
	2.45	UPDATED T(2)	1200 - 1400	333
8 May 1981	4.38	UNUPDATED 5 Day		318
	4.47	UNUPDATED 1 Day		323
	2.07	Minimum	0000 - 2359	158
	6.29	UPDATED T(.25)	1000	421
	5.21	UPDATED T(.25)	1200	362
	3.24	UPDATED T(.25)	1400	257
	4.47	UPDATED T(4)	1000 - 1400	323
	3.80	UPDATED T(2)	1200 - 1400	287

Table VI — Hurlbert Field, FL to Ft. Bragg, NC

DATE	RMS ERROR (MHz)	MODE	TIME (Z)	10.7 CM FLUX
7 May 1981	4.05	UNUPDATED 5 Day		329
	3.00	UNUPDATED 1 Day		282
	2.31	Minimum	0000 - 2359	223
	7.28	UPDATED T(.25)	1000	461
	4.96	UPDATED T(.25)	1200	366
	4.02	UPDATED T(.25)	1400	328
	5.09	UPDATED T(4)	1000 - 1400	371
	4.14	UPDATED T(2)	1200 - 1400	333
8 May 1981	5.39	UNUPDATED 5 Day		318
	5.52	UNUPDATED 1 Day		323
	2.41	Minimum	0000 - 2359	172
	8.06	UPDATED T(.25)	1000	421
	6.56	UPDATED T(.25)	1200	362
	3.80	UPDATED T(.25)	1400	257
	5.52	UPDATED T(4)	1000 - 1400	323
	4.58	UPDATED T(2)	1200 - 1400	287

Table VII — MacDill AFB, FL to Ft. Bragg, NC

DATE	RMS ERROR(MHz)	MODE	TIME (Z)	10.7 CM FLUX
7 May 1981	4.73	UNUPDATED 5 Day		329
	3.18	UNUPDATED 1 Day		282
	1.54	Minimum	0000 - 2359	210
	8.87	UPDATED T(.25)	1000	461
	5.94	UPDATED T(.25)	1200	366
	4.69	UPDATED T(.25)	1400	328
	6.10	UPDATED T(4)	1000 - 1400	371
	4.85	UPDATED T(2)	1200 - 1400	333
8 May 1981	5.36	UNUPDATED 5 Day		318
	5.49	UNUPDATED 1 Day		323
	2.58	Minimum	0000 - 2359	174
	8.00	UPDATED T(.25)	1000	421
	6.51	UPDATED T(.25)	1200	362
	3.82	UPDATED T(.25)	1400	257
	5.49	UPDATED T(4)	1000 - 1400	323
	4.58	UPDATED T(2)	1200 - 1400	287

2.5 The Updated Model and Temporal Perishability

Because of the disturbed solar conditions under which this experiment was conducted, the results for the update technique employing a single point update for the full day showed only minor improvement in the forecast over the standard method of employing a running average of the solar 10.7 cm flux. This possibility has been advertised in the past by statements to the effect that the temporal and spatial perishability of the model update technique needed to be investigated under a number of geographies, times, and solar conditions.

The conditions under which the Solid Shield data was collected has given us good reason to investigate the temporal perishability of an update. One approach to investigating the question is to impose an RMS error limit over which an update can not exceed and to perform a new update at each point where the limit is exceeded. The mean time between updates over the day gives a measure of temporal perishability. Initially, a 1 MHz RMS error was imposed and the computer performed updates using the control path as a basis for the update. When the accumulated RMS error exceeded 1 MHz, a new update was performed. That point provides the starting point for the evaluation of a new effective 10.7 cm flux and the calculation of a new RMS error. The resulting effective 10.7 cm flux was then used to make the calculation for the experimental path of interest and the RMS error was accumulated as time progressed.

The result of this procedure is shown in figure 10 in graphical form. The top plot in figure 10 indicates the application of this update scheme to the control path between Hurlbert and Norfolk for 7-8 May. Each discontinuity represents a time where a new update occurred yielding a new effective 10.7 cm flux and the beginning of a new RMS error calculation. The resulting times and effective fluxes were then used to drive the update over paths apart from the control path. This update calculation applied to the experimental paths is the essence of the remainder of figure 10 and all of figure 11. The center plot in figure 10 indicates the application of the update to the path between Norfolk and MacDill. Note that the total RMS error for the two days is near the 1 MHz imposed limit. The same effective fluxes were next applied to the Camp Le Jeune to Norfolk path utilizing the control path update. The RMS errors are somewhat worse, but still near 1 MHz.

Figure 11 shows the update scheme as it applies to the paths offset from Norfolk. The top plot indicates the Ft. Bragg to Hurlbert path utilizing effective fluxes derived from the control path. The RMS errors again are near 1 MHz. The middle plot demonstrates the application of the technique to the Ft. Bragg to MacDill circuit and the bottom plot demonstrates the application to the Ft. Bragg to Driver circuit. The theme derived from figures 10 and 11 is that in the disturbed environment where MINIMUF was a poor fit to the actual maximum usable frequency, we were able to apply MINIMUF in time segments somewhat less than 24 hours and obtain an extremely good fit over all the paths. Reiterating, it appears that information derived from the one control path may allow an extremely accurate calculation over all the other paths in the local area. The technique suffers in this disturbed case in that the forecast appears to be good for only two to three hours with 1 MHz accuracy.

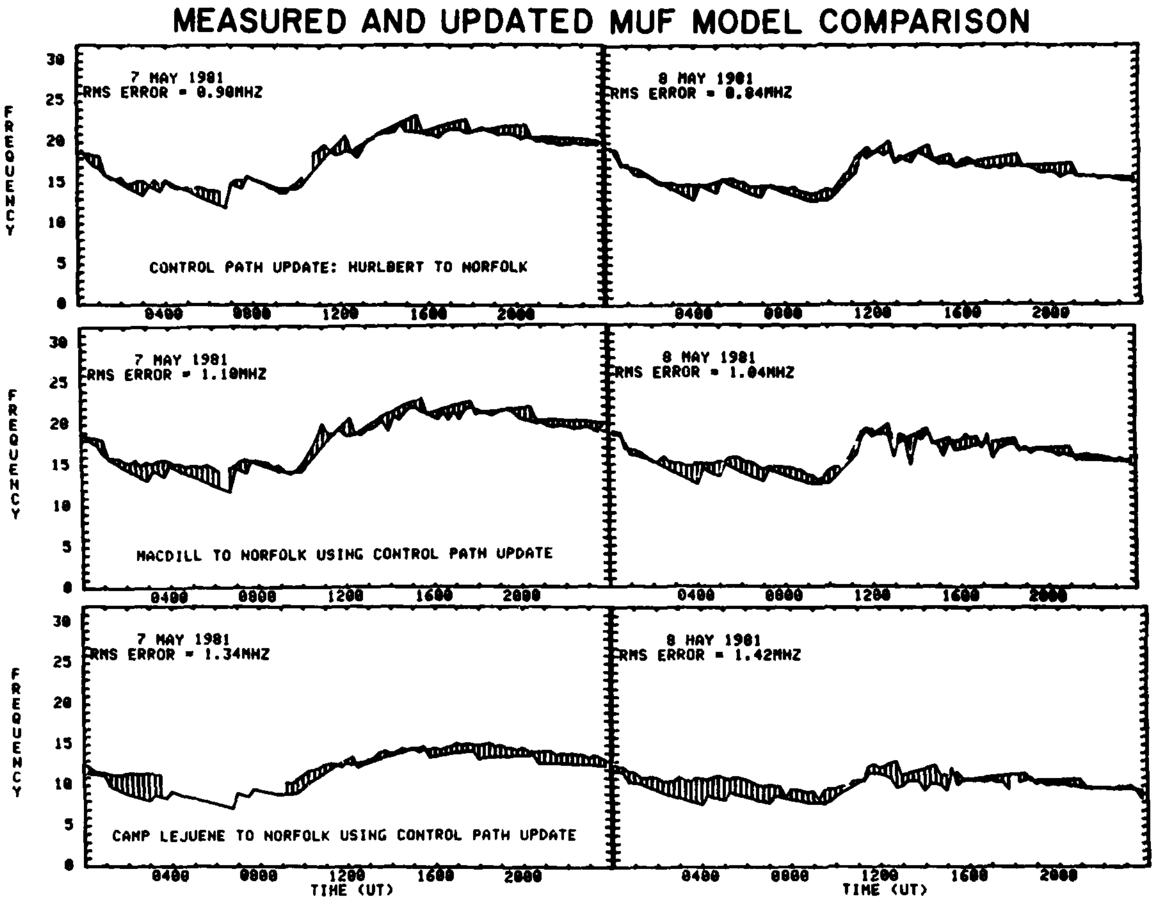

Fig. 10 — A comparison of the measured MUF and updated model of the MUF for the circuits monitored by the Norfolk receiver. The Hurlbert to Norfolk path was the control circuit from which tl e update parameter was derived.

MEASURED AND UPDATED MUF MODEL COMPARISON

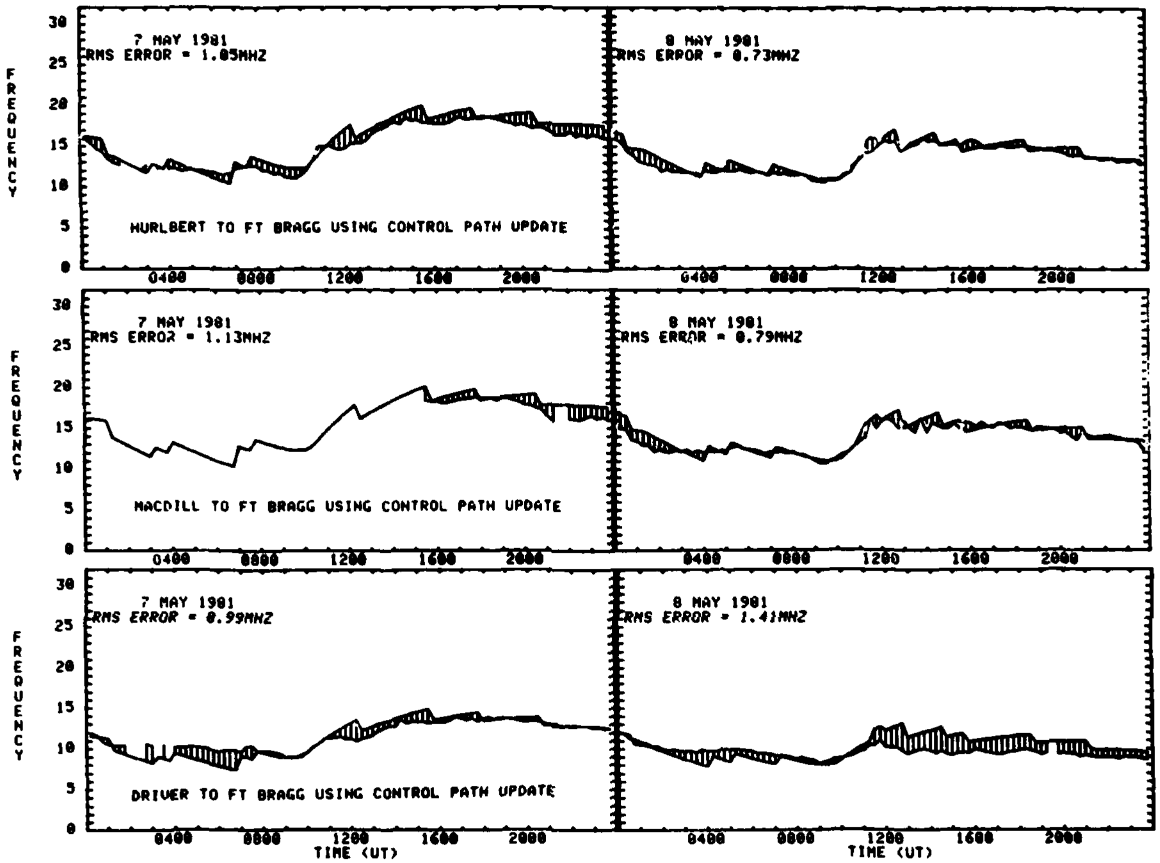

Fig. 11 — A comparison of the measured MUF and the updated model of the MUF for the circuits monitored by the Ft. Bragg receiver. The update parameter was derived from the Hurlbert to Norfolk circuit.

Tables VIII and IX list the result of this update scheme in more detail for May 7 and 8 respectively. In these tables, RMS errors are shown for the 5 day unupdated MINIMUF over the time segment indicated. Also shown for each time segment are the RMS errors in the updated mode and the absolute minimum RMS error that could be obtained by minimizing the MINIMUF calculation over the given time segment. Also listed with each of these calculations is the computed effective 10.7 cm flux. Note that with the update scheme we have applied, the update as derived over one path applies quite well over other paths apart from the control path. In addition, the update approaches the absolute minimum possible with MINIMUF. The reduction of the RMS error by the update is given numerically by Tables VIII and IX and graphically in figures 12 and 13.

3.0 Conclusions

Upon initial examination of this data set, it became clear that the solar-geophysical driving functions related to the solar activity, especially the geomagnetic activity, created diurnal maximum usable frequency variations which did not compare well to the MINIMUF model. As a result, the initial technique, whereby the model was updated at one point in the morning and returned a good fit to measurements for the rest of the day, was inappropriate. Hence, the opportunity to test a technique which would yield some information on temporal perishablility under distrubed conditions presented itself. The initial analysis presented indicates that by utilizing the mode of operation in which an error no greater than 1 MHz RMS is imposed, the update degrades to that level in about 3 hours. One must remember that the data on which these calculations are based are hand scaled. As a result, human scaling error leads to data which are noisy. Since the update is performed at a single potentially noisy point, one might expect larger variations in the index used to drive the computations. The effect of the human interpretation will not be determined adequately until automated recording of the maximum usable frequency can be accomplished. However, even under these conditions, the update technique worked extremely well over all paths used in this study.

The analysis presented herein lends further credance to the idea that marrying oblique sounding systems with PROPHET type technology could greatly extend the capabilities of both approaches to channel evaluation as applied to tactical scenarios. The oblique sounders strength is its ability to measure propagation parameters accurately over the circuit for which it is operating, but it offers no capability to directly extrapolate this information to either other paths or forward in time. The PROPHET system has shown good capability of providing MUF estimates both forward in time and to other paths, but precision over any one path suffers. The update technique being investigated by NRL appears to optimize the strong points of each of these systems.

Table VIII — RMS error (MHz) of model calculations

7 MAY 1981				CONTROL PATH										
TIME SPAN (s)	TIME SPAN DURATION		10 7 cm FLUX	HURLBERT NORFOLK	10 7 cm FLUX	MacDILL NORFOLK	10 7 cm FLUX	LEJEUNE NORFOLK	10 7 cm FLUX	DRIVER FT BRAGG	10 7 cm FLUX	HURLBERT FT BRAGG	10 7 cm FLUX	MacDILL FT BRAGG
0000 0115	1 Hr 15 Min	UNUPDATED	329	7 71	329	7 48	329	3 09	329	4 43	329	6 97	NO DATA	NO DATA
		UPDATED	173	94	173	83	173	68	173	46	173	1 02		
		MINIMUM	180	63	163	62	193	33	171	45	154	52		
0115 0315	2 Hr	UNUPDATED	329	7 91	329	7 20	329	2 60	329	4 01	329	7 70		
		UPDATED	130	91	130	1 27	130	2 63	130	1 48	130	86		
		MINIMUM	142	71	153	68	220	78	172	76	124	80		
0315 0400	45 Min	UNUPDATED	329	5 20	329	4 21	329	88	329	1 86	329	5 28		
		UPDATED	187	77	167	1 54	167	2 68	167	1 87	167	25		
		MINIMUM	182	48	206	51	287	14	238	01	180	02		
0400 0700	3 Hr	UNUPDATED	329	2 84	329	2 04	NO DATA	NO DATA	329	75	329	2 98		
		UPDATED	213	1 00	213	1 67			213	1 73	213	74		
		MINIMUM	233	77	261	88			304	62	215	74		
0700 0745	45 Min	UNUPDATED	329	91	329	1 37			329	1 32	329	36		
		UPDATED	339	72	339	1 18			338	1 19	338	46		
		MINIMUM	365	44	387	67			422	47	323	32		
0745 1230	4 Hr 45 Min	UNUPDATED	329	2 28	329	2 53	329	2 24	329	1 19	329	1 10		
		UPDATED	424	99	424	1 07	424	1 14	424	89	424	1 24		
		MINIMUM	425	99	439	1 02	470	94	382	79	370	78		
1230 1545	3 Hr 15 Min	UNUPDATED	329	81	329	86	329	52	329	98	329	96		
		UPDATED	334	91	334	98	334	46	334	1 06	334	1 07		
		MINIMUM	314	64	308	52	346	37	287	32	290	40		
1545 1800	2 Hr 15 Min	UNUPDATED	329	3 15	329	3 06	329	54	329	1 97	329	2 88	329	
		UPDATED	273	97	273	96	273	90	273	59	273	98	273	76
		MINIMUM	251	41	254	56	307	15	253	25	248	26	253	27
1800 2045	2 Hr 45 Min	UNUPDATED	329	4 04	329	4 62	329	1 52	329	2 75	329	4 38	329	4 14
		UPDATED	234	93	234	84	234	1 20	234	32	234	1 06	234	82
		MINIMUM	218	63	224	68	274	45	229	29	215	72	220	62
2045 2400	3 Hr 15 Min	UNUPDATED	329	6 34	329	6 41	329	2 39	329	3 62	329	6 20	329	6 47
		UPDATED	201	59	201	75	201	1 21	201	14	201	1 23	201	1 61
		MINIMUM	190	21	187	26	241	22	201	14	174	36	188	38
0000 2400	24 Hr	UNUPDATED	329	4 56	329	4 33	329	2 01	329	2 39	329	4 06	329	4 73
		UPDATED		90		1 10		1 34		99		1 06		1 13
		MINIMUM												

Table IX — RMS error (MHz) of model calculations

8 MAY 1981				CONTROL PATH										
TIME SPAN (s)	TIME SPAN DURATION		10 7 cm FLUX	HURLBERT-NORFOLK	10 7 cm FLUX	MacDILL NORFOLK	10 7 cm FLUX	LEJEUNE-NORFOLK	10 7 FLUX	DRIVER-FT BRAGG	10.7 cm FLUX	HURLBERT-FT BRAGG	10.7 cm FLUX	MacDILL FT BRAGG
0000 0045	45 Min	UNUPDATED	318	6 32	318	6 31	318	2.98	318	3.86	318	6.20	318	6.80
		UPDATED	183	50	183	31	183	78	183	32	183	94	183	1.40
		MINIMUM	179	46	177	13	208	16	181	31	163	.25	152	.32
0045 0415	3 Hr 30 Min	UNUPDATED	318	6 81	318	6 34	318	2 61	318	3 58	318	6.96	318	6.80
		UPDATED	147	86	147	1 23	147	2 00	147	98	147	1 02	147	1 12
		MINIMUM	153	81	161	1 06	213	90	174	61	129	63	130	88
0415 0515	1 Hr	UNUPDATED	318	2 90	318	2 22	318	59	318	1 06	318	3 58	318	3 10
		UPDATED	208	79	208	1 28	208	2 48	208	1 16	208	88	208	41
		MINIMUM	228	54	246	51	341	45	264	36	188	36	203	38
0515 0715	2 Hr	UNUPDATED	318	67	318	48	318	1 21	318	24	318	1 72	318	1 07
		UPDATED	269	89	269	1 41	269	1 96	269	88	269	72	288	.38
		MINIMUM	298	46	322	47	400	24	323	.22	246	47	273	.36
0715 1130	4 Hr 15 Min	UNUPDATED	318	1.42	318	1.49	318	1 36	318	58	318	40	318	72
		UPDATED	342	93	342	1.00	342	1 07	342	40	342	50	342	48
		MINIMUM	383	.42	388	38	412	.58	360	39	325	38	347	48
1100 1200	30 Min	UNUPDATED	318	1.96	318	2 76	318	72	318	23	318	46	318	1 58
		UPDATED	417	.92	417	28	417	98	417	1 84	417	1 88	417	1 09
		MINIMUM	389	64	429	.08	358	17	308	15	337	08	380	78
1200 1300	1 Hr	UNUPDATED	318	78	318	1 18	318	1 32	318	1.84	318	43	318	88
		UPDATED	362	.87	362	89	362	2 00	362	2 86	362	96	362	1.23
		MINIMUM	337	.53	349	.80	289	90	230	46	325	38	376	87
1300 1445	1 Hr 45 Min	UNUPDATED	318	2 46	318	2.87	318	2 90	318	3.57	318	2.07	318	2 43
		UPDATED	285	.81	285	1.51	285	1 76	285	2 40	286	58	285	1 11
		MINIMUM	249	59	244	1.31	195	56	170	33	249	28	242	86
1445 1545	1 Hr	UNUPDATED	318	4.86	318	4 80	318	3.82	318	4 91	318	3 77	318	4 09
		UPDATED	211	78	211	1.02	211	1 43	211	2.24	211	38	211	90
		MINIMUM	195	.40	197	.82	173	97	134	10	206	31	198	32
1545 1845	3 Hr	UNUPDATED	318	7 12	318	6.37	318	4 65	318	5.77	318	5 62	318	5.63
		UPDATED	171	98	171	1 09	171	75	171	1 70	171	72	171	88
		MINIMUM	157	.75	172	1 09	153	50	120	28	170	72	170	88
1845 2115	2 Hr 30 Min	UNUPDATED	318	9 29	318	8.78	318	5 77	318	6.81	318	7 63	318	7 67
		UPDATED	141	97	141	61	141	61	141	1 52	141	62	141	88
		MINIMUM	128	80	133	.43	127	38	102	23	134	52	134	98
1115-2400	2 Hr 45 Min	UNUPDATED	318	10.22	318	9.56	318	6 29	318	7 18	318	8 88	318	6.73
		UPDATED	113	24	113	.46	113	36	113	89	113	30	113	40
		MINIMUM	112	.20	121	.18	112	35	102	49	111	28	114	.44
0000-2400	24 Hr	UNUPDATED	318	6 13	318	5 76	318	3 70	318	4 38	318	5 39	318	5.38
		UPDATED		84		1 04		1 42		1 41		73		79
		MINIMUM												

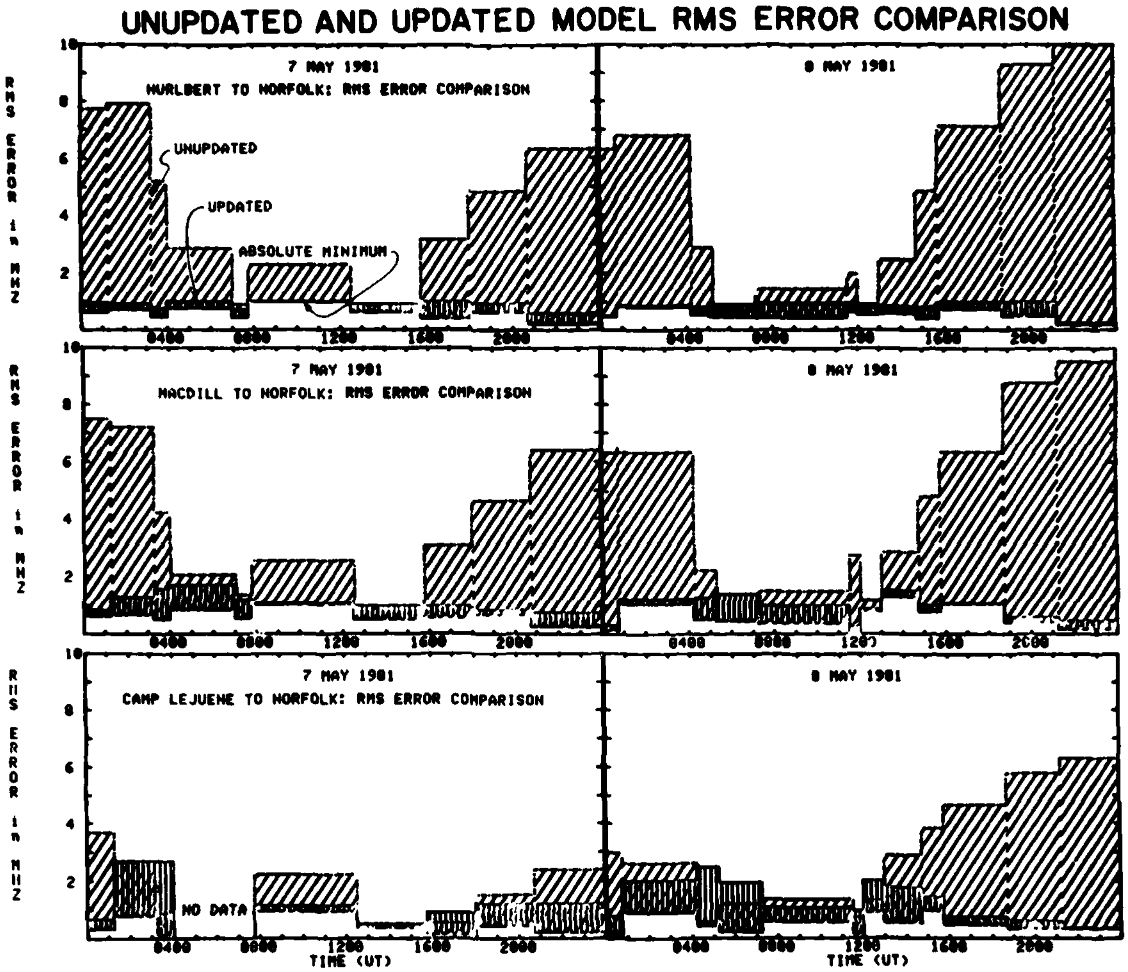

Fig. 12 — A histogram representation of the improvement in model performance by employing the update technique on Norfolk receiver data

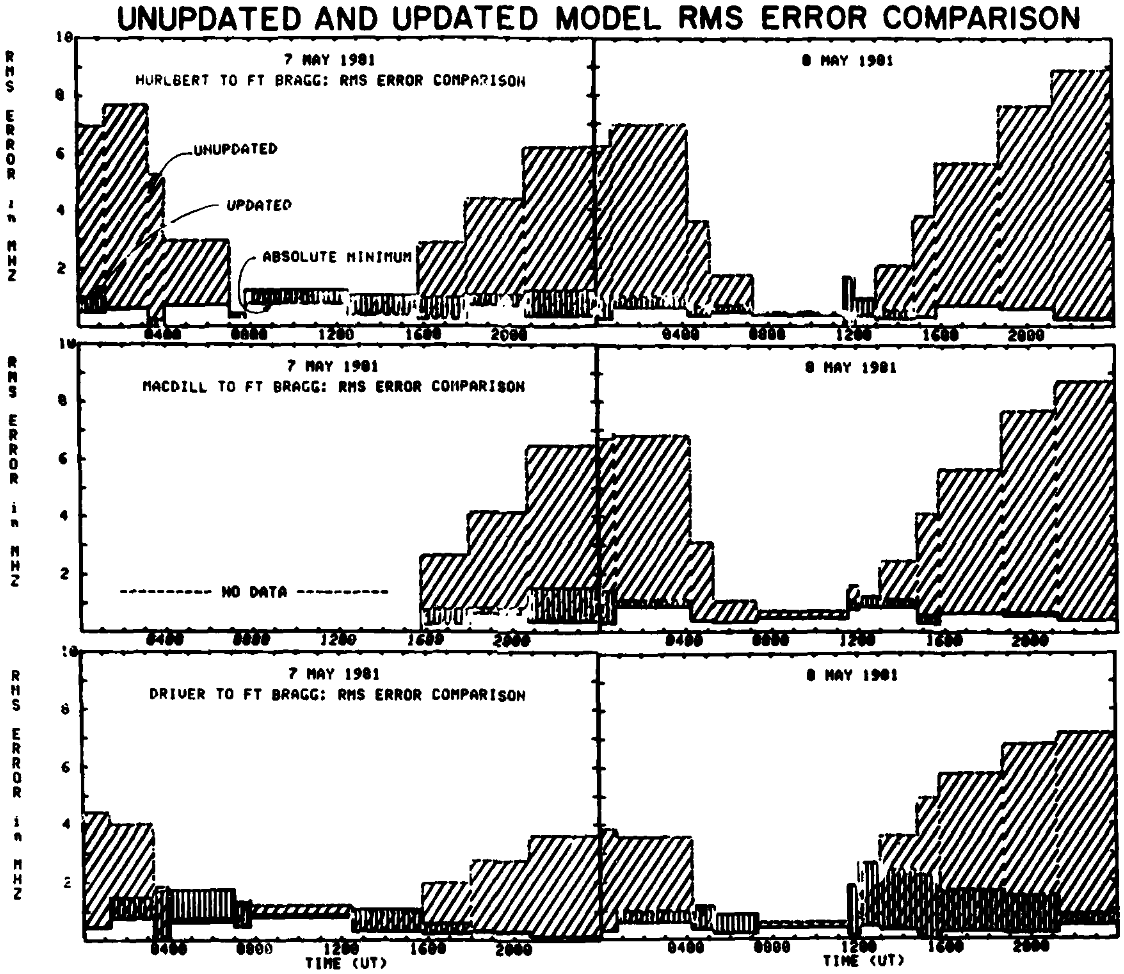

Fig. 13 — A histogram representation of the improvement in model performance by employing the update technique on Ft. Bragg receiver data

4.0 Recommendations

It is clear that solar activity has a profound influence on the success of frequency management systems, but the MINIMUF 3.5 code with which we are working cannot yet adequately handle magnetic activity perturbations. It is recommended that a suitable magnetic activity variable be incorporated in the MINIMUF code to partially ameliorate this problem. This will not be a simple task.

The model update scheme admittedly needs further verification and testing. However, with the appropriate cautions, it might be a useful interim technique to the military frequency controller. One could manually update PROPHET every 30 minutes using a control path. These manual updates could then be tracked automatically as was done in the example presented herein and update indices generated. These numbers could then be transmitted to users of PROPHET terminals who could perform frequency predictions and estimations, and employ propagation tactics over a local area where the control path is operating. Properly monitored, this work could form the basis of further validation of the technique. In the future it is envisioned that this approach could be carried out automatically.

5.0 Acknowledgments

As with any scientific endeavor, many people make contributions to the project's success and should be recognized. The authors gratefully acknowledge the following individuals. Messers Fred Feldt, Tom Priddy, and Larry Quinn helped to man the field sites and to collect the photographic data. Mr. Bill Juchsch, the Science Advisor at CINCLANTFLT was indispensible to working out several difficulties at NAVCAMSLANT. MSGT Glenn Jensen was responsible for getting the Mac Dill transmitter operational for us in short order. Individuals in the Directorate of Combat Doctrine and Developement at Headquarters of the U.S. Army Institute for Military Assistance at Ft. Bragg deserve recognition for providing the Ft. Bragg Field Site. Specifically, MSGT's Jan Walker and Bill Cason are recognized for their competant assistance and "can-do" attitude which seems to permeate all the Special Forces with whom we had contact. Finally, Ms Peggy Hoover spent long hours organizing and scaling the sounder data. Thank you all!

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APPENDIX A-SUMMARY OF NORFOLK LOG

Apr. 30	Security clearance problem. No data collected.
May 1	Security clearance problem. No data collected.
May 2	Security clearance problem. No data collected.
May 3	Data collection began at 0600Z. Receiver initially programmed to receive Hurlbert Field, FL, Bogue Field, NC and Driver, VA. Shaw AFB, SC also transmitting but during same five minute interval as Hurlbert.
May 4	Due to receiver AGC characteristics and the short distance between transmitter and receiver, ground wave was the only mode of propagation being displayed on the Driver channel. This broadband groundwave provides the Tech Controllers no useful frequency management information. Bogue Field off the air at 2200Z.
May 5	Bogue Field back on at 2045Z. During Bogue Field down time only one (Hurlbert) link was available for frequency management. A suggestion to request Shaw AFB or Hurlbert to transmit every five minutes, instead of 15 minutes, was turned down by CWO Paulis.
May 6	NRL requested, through non-Navy channels, and received permission to have a transmitter turned on at MacDill AFB, FL. It was programmed to transmit every five minutes and provided the needed alternate channel. MacDill was inserted in place of Driver and for the first time, three potentially useful links were received.
May 7	Bogue Field down at 0355Z-0910Z. Afternoon MUFs on all three links are depressed. SESC reports strong geomagnetic activity.
May 8	MUFs returning to normal. Signal levels increasing.
May 9	Absorption causing high LUFs on MacDill and Hurlbert links. Bogue Field exhibits strong absorption.
May 10	Depressed MUFs and increased LUFs.
May 11	MUFs significantly higher during daytime hours than previous days. Evening thunderstorms creating high broadband noise which overrides ionogram.
May 12	Hurlbert terminated transmitting at 1430Z. Shaw inserted in its place.
May 13	Shaw signal extremely weak. Request Shaw turn up power. WWV reports high geomagnetic activity. Ionograms show fading and low signal level.

May 14	Barry representative inserted Driver in place of MacDill to check a reported transmitter frequency drift. A check of the drift rate over the previous several days was done by NRL representatives at Fort Bragg, NC, who were photographing the Driver ionograms. No drift was seen. Barry representative and the Tech Control Officer decided to continue monitoring Driver anyway. Suggested use of Mt. Whitney receiver instead.
May 15	Tech Control Officer requested sync with Nea Makri, Greece at 0000Z which requires taking down two stations due to sweep overlap. No apparent operational reason for this interruption. This created an additional 12 hour gap in data. Spread-F being seen on both Bogue Field and Nea Makri. Nea Makri faded out at 1000Z. Resync with Driver and Shaw at 1200Z. Strong evening thunderstorms wiped out all three stations.
May 16	Very low MUFs. Fading and absorption on all channels. Lost sync with Shaw. Inserted MacDill.
May 17	Slowly increasing MUFs. Slightly higher signal level.
May 18	Barry representative hasn't returned to check drift. (See May 14) Inserted Shaw in place of Driver. MUFs and LUFs appear normal. Some spread-F and possible nose extension on Bogue Field data. Started analog tape recording at 2300Z to test purported capability to record ionogram information.
May 19	Tape recording terminated by Tech Control Warrant Officer at 1400Z. We explained we were using a recording technique given to us by Barry Communications, but he still felt we would damage the equipment. Data collection terminated at 20/0000Z.

Appendix B — MINIMUF Predictions over experimental paths

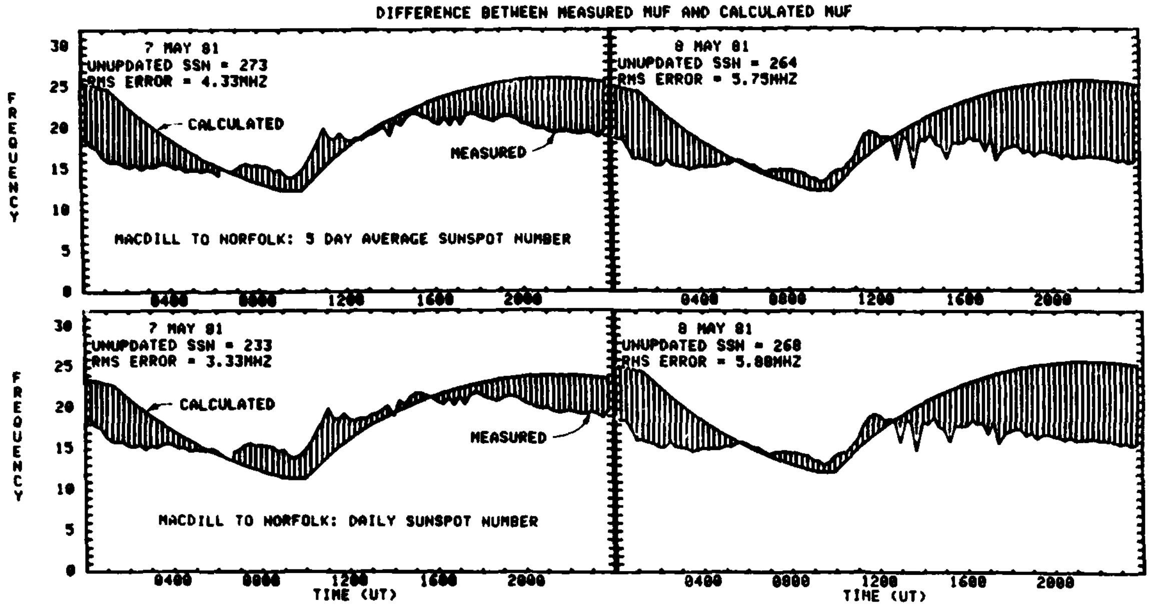

Figure 1

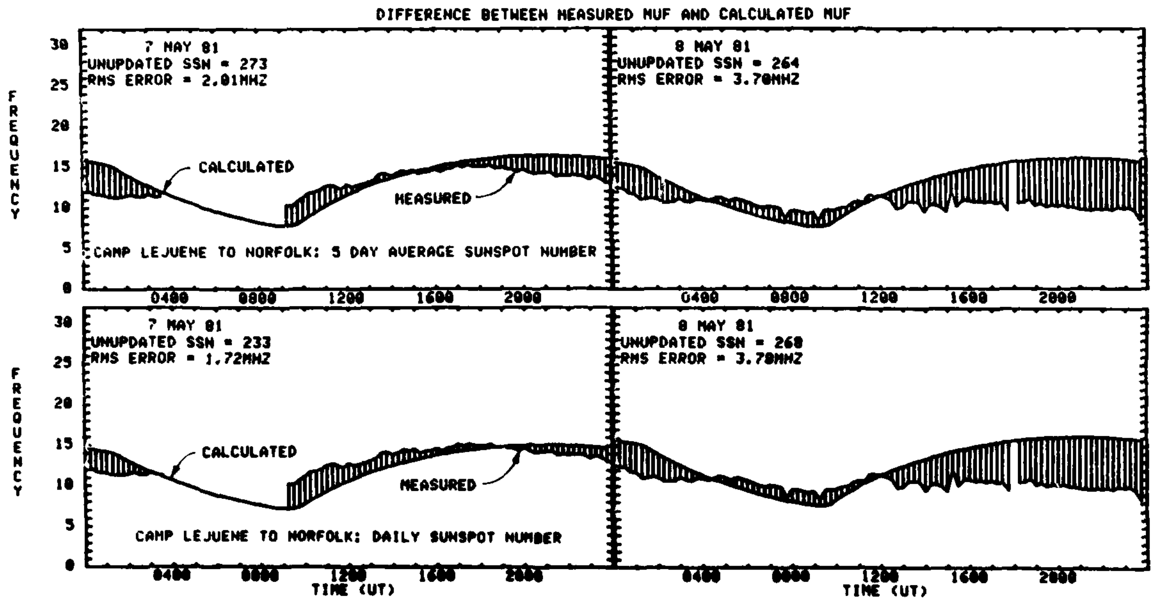

Figure 2

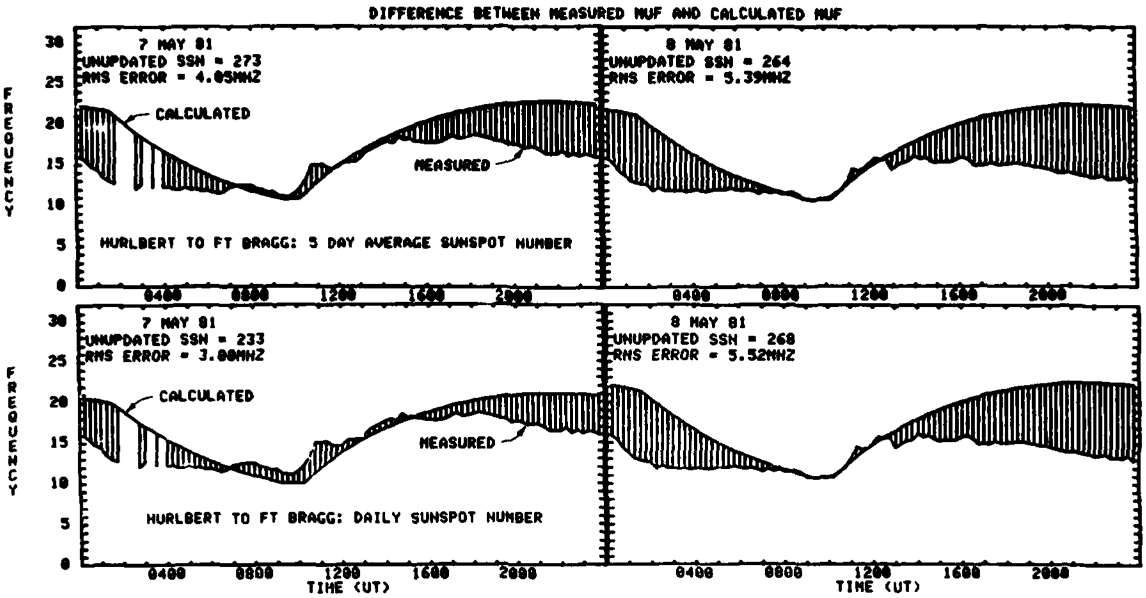

Figure 3

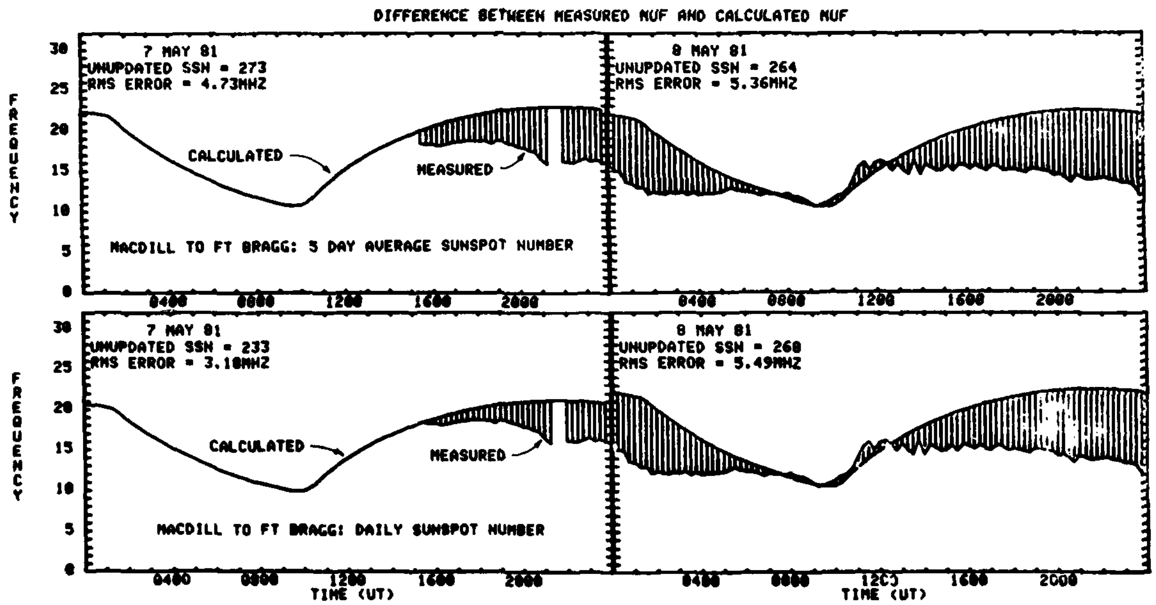

Figure 4

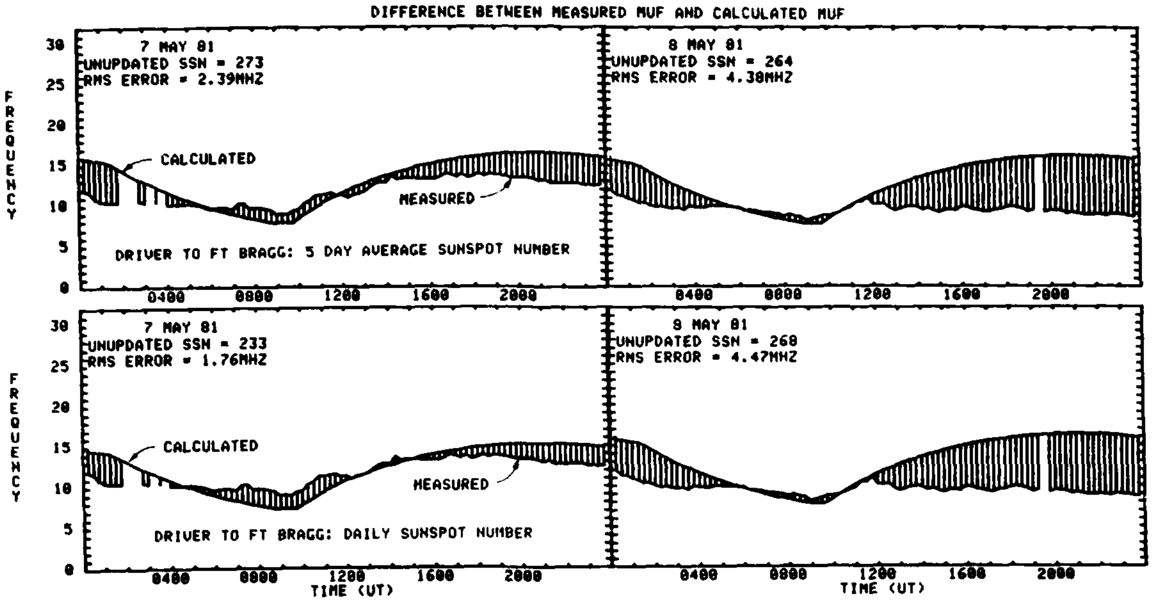
DIFFERENCE BETWEEN MEASURED MUF AND CALCULATED MUF
7 MAY 81
UNUPDATED SSN = 273
RMS ERROR = 2.39MHZ
8 MAY 81
UNUPDATED SSN = 264
RMS ERROR = 4.38MHZ
FREQUENCY
CALCULATED
MEASURED
DRIVER TO FT BRAGG: 5 DAY AVERAGE SUNSPOT NUMBER
7 MAY 81
UNUPDATED SSN = 233
RMS ERROR = 1.76MHZ
8 MAY 81
UNUPDATED SSN = 268
RMS ERROR = 4.47MHZ
CALCULATED
MEASURED
DRIVER TO FT BRAGG: DAILY SUNSPOT NUMBER
TIME (UT)
TIME (UT)

Figure 5

DATE

ILME

8